TC-permitting GCM simulations of hurricane frequency response to sea surface temperature anomalies projected for the late 21st century

Ming Zhao[1,2] and Isaac M. Held[1]

[1]Geophysical Fluid Dynamics Laboratory / NOAA, Princeton, New Jersey, USA

[2]University Corporation for Atmospheric Research

Corresponding author address:

Dr. Ming Zhao

Geophysical Fluid Dynamics Laboratory / NOAA

Princeton University Forrestal Campus

201 Forrestal Road, Princeton, New Jersey 08540-6649

Phone: (609) 452-6500

Fax: (609) 987-5063

Abstract. A tropical cyclone permitting global climate model is used to explore hurricane frequency response to sea surface temperature (SST) anomalies generated by coupled models for the late 21st century using the IPCC AR4 A1B scenario. Results are presented for SST anomalies computed by averaging over 18 CMIP3 models as well as from individual realizations from 8 different models. For each individual ocean basin, there generally exists large inter-model spread in the magnitude and (for a few basins) even the sign of the response in hurricane frequency to warming among the different SST projections. These sizable variations in response are explored to understand features of SST distributions that are important for storm genesis in individual basins. In the N. Atlantic, the E. Pacific and the S. Indian basins, most (72-86%) of the inter-model variance in storm frequency response can be explained by a simple relative SST index defined as a basin's storm development region SST minus the tropical mean SST. The explained variance is significantly lower in the S. Pacific (48%) and much lower in the W. Pacific basin (27%). When the W. Pacific is separated into 3 sub-basins, 42% of the inter-model variance in the main development region can still be accounted for by the simple relative SST index while storms in South China Sea and the Eastern W. Pacific correlate to SSTs in the Central and Eastern Pacific.

Six atmospheric parameters are utilized to probe changes in tropical atmospheric circulation and thermodynamical properties relevant to storm genesis. While all present strong correlation to storm frequency response in three basins, one parameter measuring the large-scale tropospheric convective activity stands out as a skillful variable in explaining the simulated differences for all basins. Globally, in addition to a modest reduction of total storm frequency, the simulations exhibit a small but robust eastward and poleward migration of genesis frequency in both the N. Pacific and the N. Atlantic oceans upon warming. This eastward migration of storms can also be explained by changes in large-scale convective activities. The implication on the role of convection in controlling regional and global tropical

cyclone frequency response to 21st century warming is discussed.

Table 1.

1. Results

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Table 2.

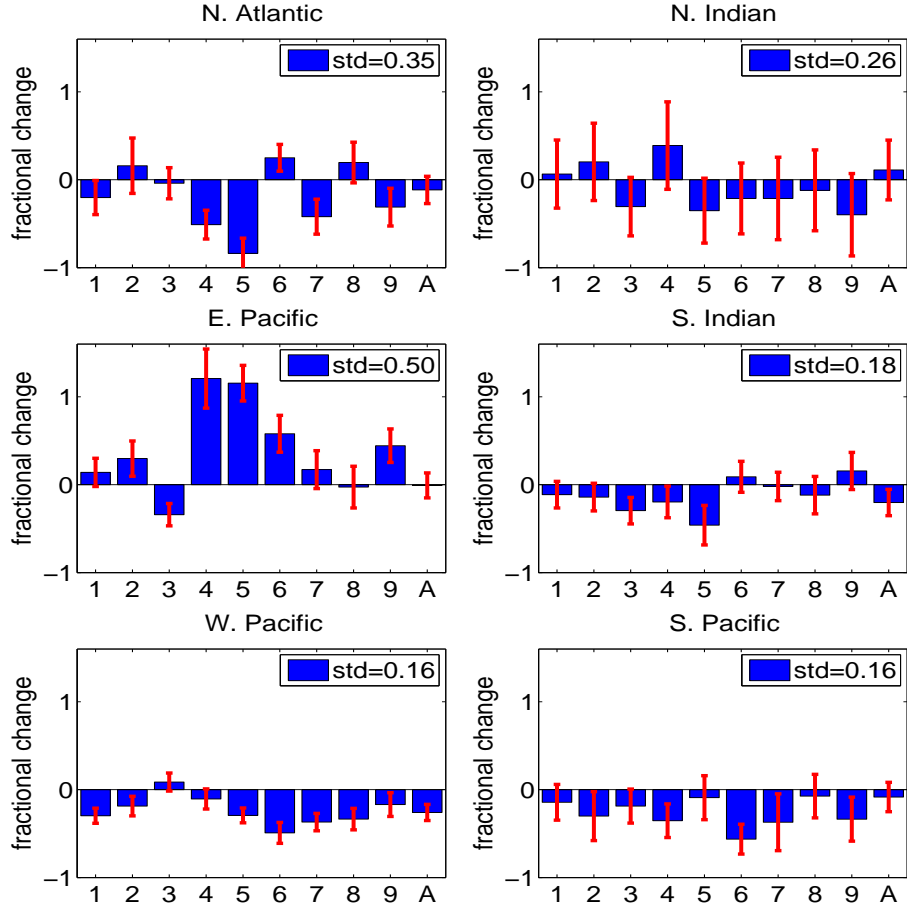Figure 5.

Figure 6.

Figure 7.

Figure Captions

Figure 1. Fractional changes in annual hurricane count for a) N. Atlantic, b) E. Pacific, c) W. Pacific, d) N. Indian, e) S. Indian, and f) S. Pacific from 10 (1-A; see Table 1) SST warming experiments and the control experiment. Error bars show the 90% confidence level assuming the sampling distributions are normally distributed.
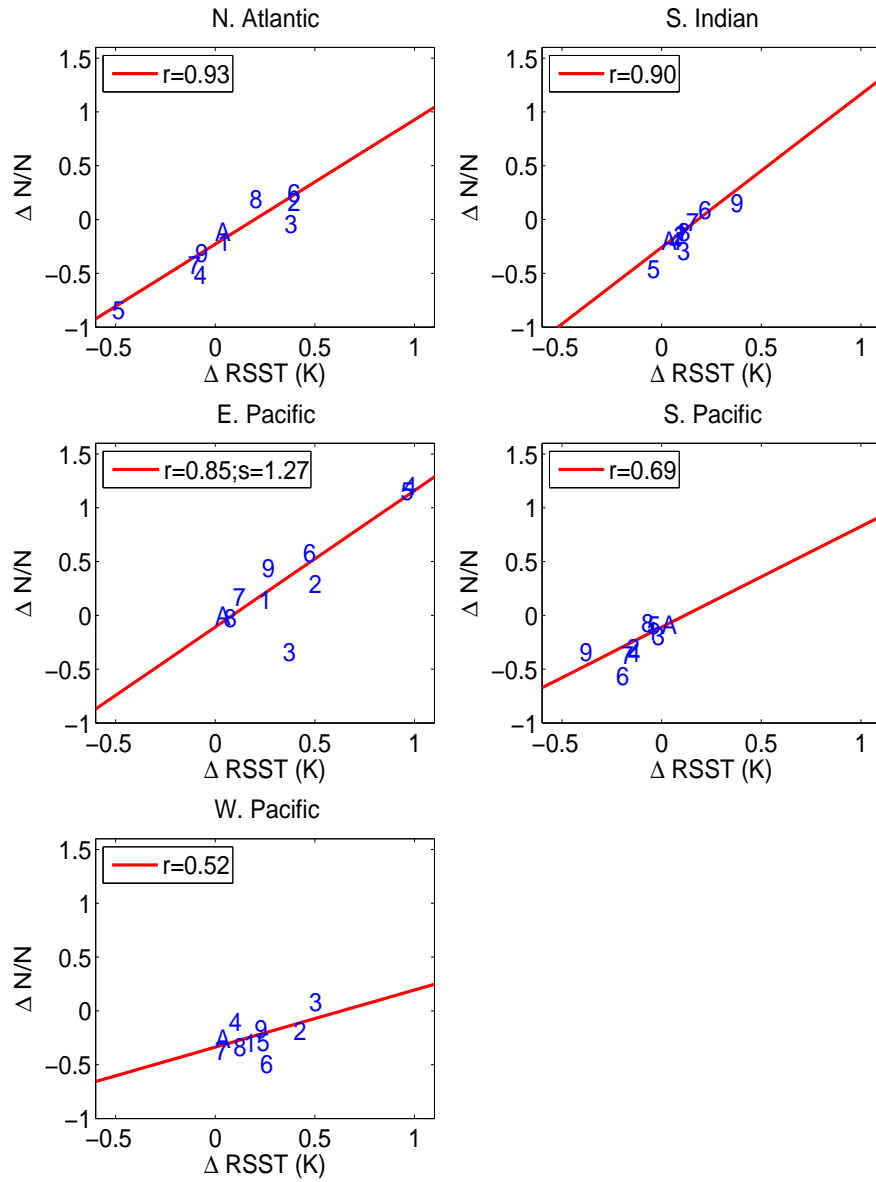
Figure 2. Scatter plot of the fractional changes in annual hurricane count ($\Delta N/N$) versus changes in a relative SST index ($RSST$, defined as a basin's storm development region SST minus tropical mean SST, see text for details) for a) N. Atlantic, b) E. Pacific, c) W. Pacific, d) S. Indian and e) S. Pacific basins. Lines are linear regressions; legend shows correlation coefficient.
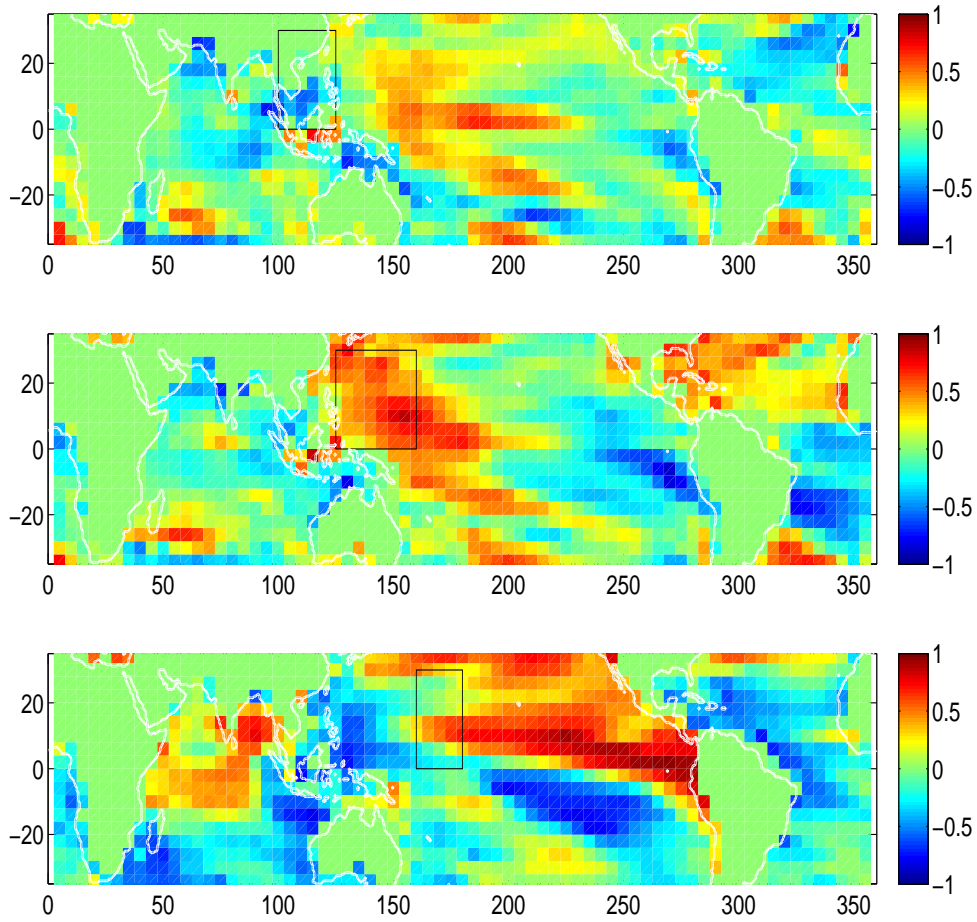
Figure 3. Correlation map between the local change in relative SST (warming minus control) and the change in hurricane genesis frequency from 3 sub-basins in the W. Pacific: a) SCS; b) MDR and c) EWP. Black boxes show the boundary of each region where storm genesis frequency is computed.
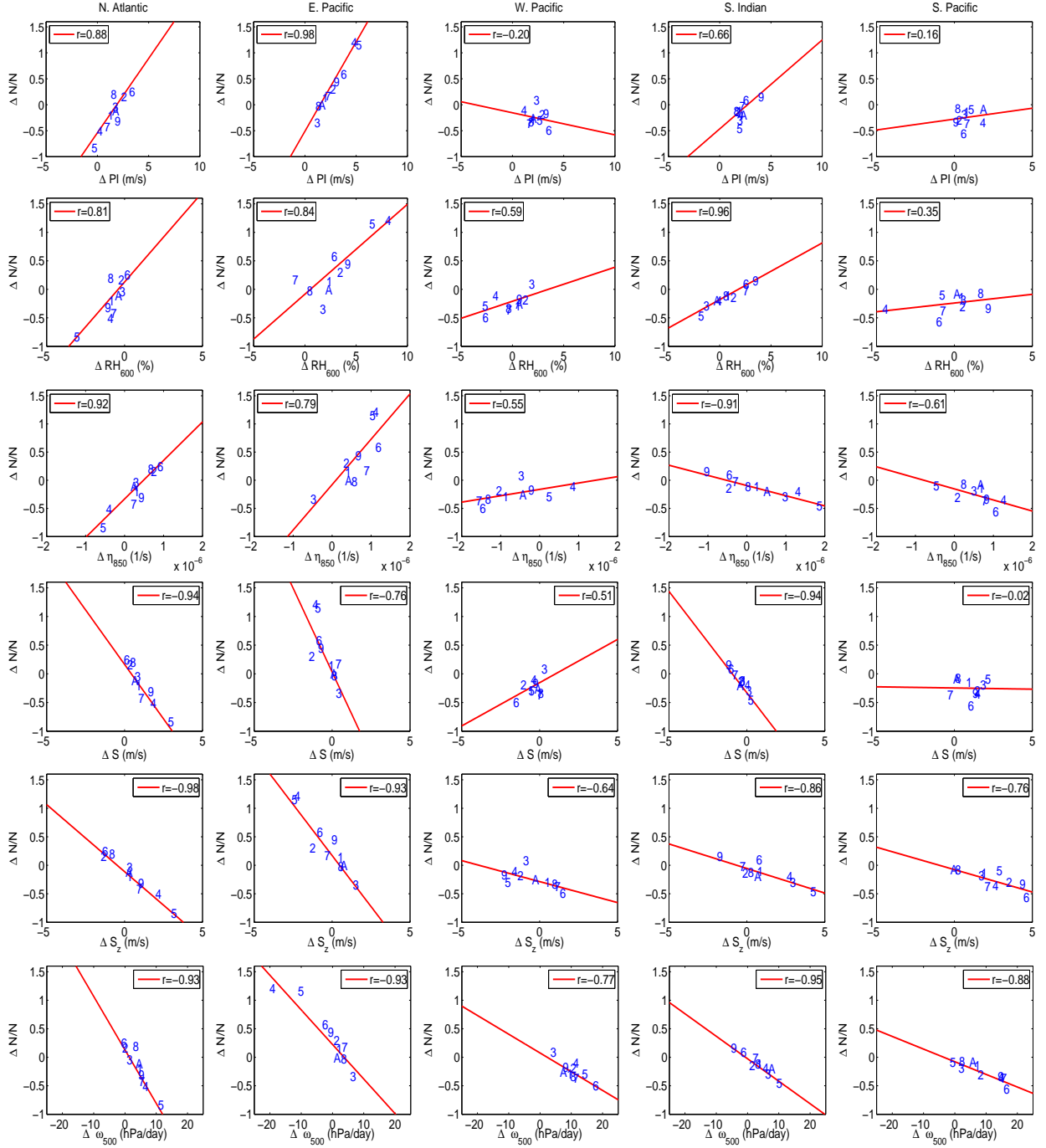
Figure 4. Scatter plots of the fractional changes in annual hurricane count ($\Delta N/N$) versus changes in each of the 6 indices of atmospheric parameters for 5 ocean basins. Left to right columns: N. Atlantic, E. Pacific, W. Pacific, S. Indian, S. Pacific. Top to bottom: potential intensity (PI), 600 hPa relative humidity (RH_{600}), 850 hPa vorticity (η_{850}), magnitude of vertical shear of vector wind (S) between 200 and 850 hPa, vertical shear of zonal wind (S_z) between 200 and 850 hPa, and 500 hPa vertical pressure velocity (ω_{500}).
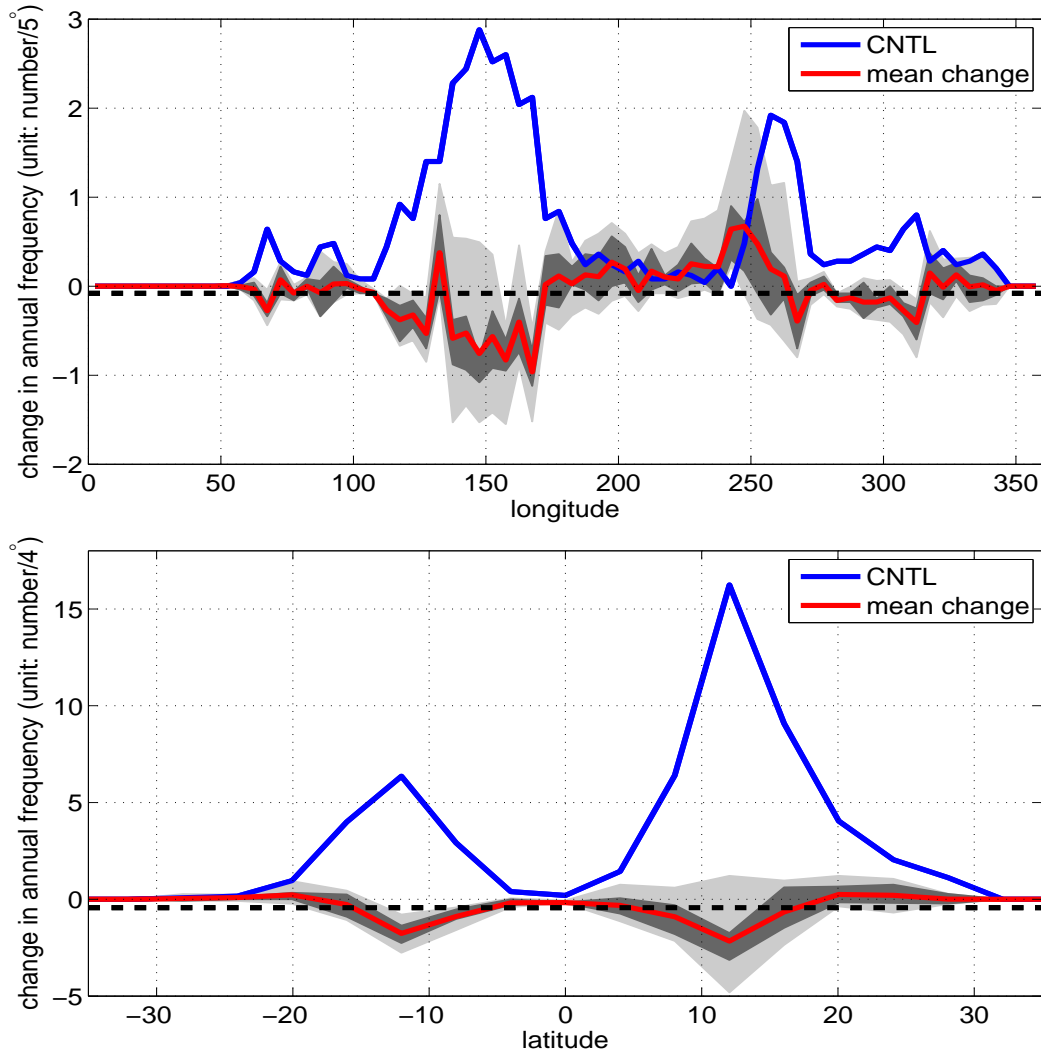
Figure 5. a) Changes in longitudinal distribution of N. Hemisphere (N.H.) hurricane frequency from warming and control experiments (unit: number/year/5°). Red: ensemble mean change from all 10 warming experiments; dark shading: central 50% range (25-75%); light shading: central 80% range (10-90%). Blue line: longitudinal distribution of N.H. hurricane frequency from the control simulation. Black dashed line show the averaged change over all N.H. genesis region. b) As in a) except for the latitudinal distribution (unit: number/year/4°).
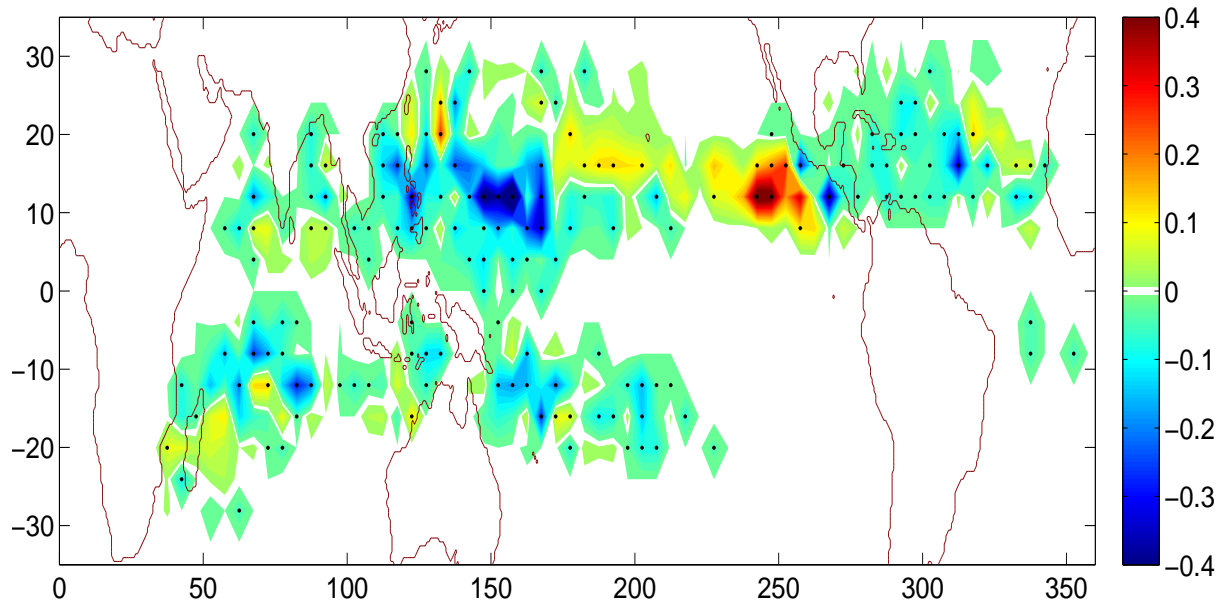
Figure 6. Geographical distribution of the changes in annual hurricane frequency averaged from 10 warming experiments and the control experiment [unit: number/year per $4°\times5°$ (latxlon)]. Stippled area denote grid boxes where at least 80% of the models agree on the sign of the change.
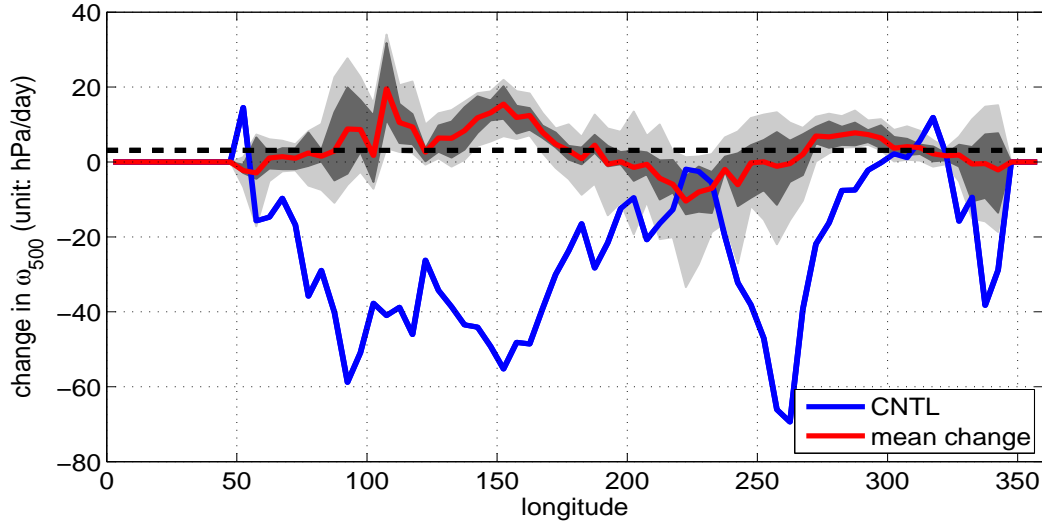
Figure 7. As in Fig. 5a except for changes in longitudinal distribution of N. Hemisphere 500 hPa vertical pressure velocity ω_{500} between warming and control experiments (unit: hPa/day/5°). ω_{500} are weighted by TC genesis frequency from the control simulation following the same procedure as that in Fig. 2.

Tables

number	ACRONYM	Description of Modeling Group
1	ENSEMBLE	18-Model Ensemble Mean
2	GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory
3	GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory
4	UK-HADCM3	Hadley Centre for Climate Prediction and Research/Met Office
5	UK-HADGEM1	Hadley Centre for Climate Prediction and Research/Met Office
6	ECHAM5	Max Planck Institute for Meteorology
7	CCCMA	Canadian Centre for Climate Modelling & Analysis
8	MRI-CGCM	Meteorological Research Institute of Japan
9	MIROC-HI	Center for Climate System Research and JAMSTEC
A	P2K	Uniform 2K Warming

Table 1. A list (1-A) of the sea surface temperature warming anomalies, their acronyms and descriptions of the corresponding modeling groups.

correlation	$RSST$	PI	RH_{600}	η_{850}	S	S_z	ω_{500}
N. Atlantic	**+0.93**	**+0.88**	**+0.81**	**+0.92**	**−0.94**	**−0.98**	**−0.93**
E. Pacific	**+0.85**	**+0.98**	**+0.84**	**+0.79**	**−0.76**	**−0.93**	**−0.93**
W. Pacific	+0.52	−0.20	**+0.59**	**+0.55**	+0.51	**−0.64**	**−0.77**
S. Indian	**+0.90**	**+0.66**	**+0.96**	**+0.91**	**−0.94**	**−0.86**	**−0.95**
S. Pacific	**+0.69**	+0.16	+0.35	**+0.61**	−0.02	**−0.76**	**−0.88**

Table 2. Correlation coefficients between changes in annual hurricane frequency and changes in each of the 7 environmental indices for all 6 different ocean basins from the 10 warming experiments and the control experiment. Bold faced coefficients denote significant at the 95% confidence level.